Bounding and Shaping the Demand of Mixed-Criticality Sporadic Tasks

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Mixed-criticality sporadic tasks

Task $\tau_i$

- $C_i(\text{LO})$: WCET at low-criticality
- $C_i(\text{HI})$: WCET at high-criticality
- $D_i$: Relative deadline
- $T_i$: Period
- $L_i$: Criticality (LO or HI)

$(C_i(\text{LO}) \leq C_i(\text{HI}))$
**Mixed-criticality sporadic tasks**

\[ \tau_1 (L_1 = \text{LO}): \]

\[ \tau_2 (L_2 = \text{HI}): \]

\[ \tau_3 (L_3 = \text{HI}): \]
Mixed-criticality sporadic tasks

\( \tau_1 (L_1 = \text{LO}): \)

\( \tau_2 (L_2 = \text{HI}): \)

\( \tau_3 (L_3 = \text{HI}): \)
Mixed-criticality sporadic tasks

$\tau_1 (L_1 = \text{LO})$: 

$\tau_2 (L_2 = \text{HI})$: 

$\tau_3 (L_3 = \text{HI})$: 

A task set $\tau$ is schedulable if

$$\forall \ell \geq 0 : \sum_{\tau_i \in \tau} \text{dbf}(\tau_i, \ell) \leq \text{sbf}(\ell).$$
Schedulability analysis

A task set $\tau$ is schedulable if both A and B hold:

**A:** \[ \forall \ell \geq 0 : \sum_{\tau_i \in \tau} dbf_{LO}(\tau_i, \ell) \leq sbf_{LO}(\ell) \]

**B:** \[ \forall \ell \geq 0 : \sum_{\tau_i \in \text{HI}(\tau)} dbf_{HI}(\tau_i, \ell) \leq sbf_{HI}(\ell) \]

Mixed-criticality EDF analysis

Low-criticality mode

High-criticality mode

Time
Demand-bound functions

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{lo})$. 

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Low-criticality mode | High-criticality mode

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Demand-bound functions

Use dbfs from Baruah et al., 1990!

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i(\text{lo})$.

[Diagram showing time axis with two modes: Low-criticality mode and High-criticality mode.]

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Demand-bound functions

Each \( \tau_i \) behaves similar to a standard sporadic task with WCET \( C_i(\text{HI}) \).

Use dbfs from Baruah et al., 1990!

Each \( \tau_i \) behaves exactly like a standard sporadic task with WCET \( C_i(\text{LO}) \).
Demand-bound functions

Each $\tau_i$ behaves similar to a standard sporadic task with WCET $C_i^{(HI)}$.

Use dbfs from Baruah et al., 1990!

Each $\tau_i$ behaves exactly like a standard sporadic task with WCET $C_i^{(LO)}$.

Half-finished jobs are carried over to high-criticality mode.
**Half-finished** jobs are carried over to high-criticality mode.

To show $A \land B$, we show $A \land (A \rightarrow B)$. 

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**Restricting to the interesting cases**
Carry-over jobs

Switch to high-criticality mode

Release of $\tau_i$

Absolute deadline

$T$

$t + D_i$

Time
Carry-over jobs

Switch to high-criticality mode

Remaining scheduling window

Release of \( \tau_i \)

Absolute deadline

Time

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Switch to high-criticality mode

Remaining scheduling window

Release of $\tau_i$

Absolute deadline

$T_i$

$t + D_i$

Time
**Carry-over jobs**

Switch to **high**-criticality mode

Remaining scheduling window: $C_i(\text{HI}) - C_i(\text{LO})$

- Release of $\tau_i$
- Absolute deadline $t + D_i$

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Adjusting the demand of carry-over jobs

Release of \( \tau_i \)

Deadlines in low- and high-criticality mode

\[ t \rightarrow t + D_i(\text{lo}) \rightarrow t + D_i(\text{hi}) \]
Adjusting the demand of carry-over jobs

Switch to high-criticality mode

Release of $\tau_i$

Deadlines in low- and high-criticality mode

Switch to high-criticality mode
Adjusting the demand of carry-over jobs

Switch to **high**-criticality mode

Release of $\tau_i$

Deadlines in **low-** and **high**-criticality mode

Remaining scheduling window

Switch to **high**-criticality mode

Time

$t$

$t + D_i(\text{lo})$

$t + D_i(\text{hi})$
Adjusting the demand of carry-over jobs

Switch to high-criticality mode

Remaining scheduling window

Release of $\tau_i$

Deadlines in low- and high-criticality mode

Time

$t + D_i(\text{lo})$

$t + D_i(\text{hi})$
Adjusting the demand of carry-over jobs

Switch to **high**-criticality mode

Remaining scheduling window

Release of $\tau_i$

Deadlines in **low-** and **high**-criticality mode

Switch to **high**-criticality mode

$t + D_i(\text{lo})$

$t + D_i(\text{hi})$

$...$

Time
Demand-bound functions for high-criticality mode

\[ \text{dbf}_\text{HI}(\tau_i, \ell) \]
Demand-bound functions for high-criticality mode

\[ \text{dbf}_{HI}(\tau_i, \ell) \]

\[ \text{dbf}_{LO}(\tau_i, \ell) \]
The effect of the low-criticality relative deadline

If $D_i(\text{lo})$ is decreased by $\delta \in \mathbb{Z}$, then

\[
\text{dbf}_{\text{LO}}(\tau_i, \ell) \leadsto \text{dbf}_{\text{LO}}(\tau_i, \ell + \delta)
\]
\[
\text{dbf}_{\text{HI}}(\tau_i, \ell) \leadsto \text{dbf}_{\text{HI}}(\tau_i, \ell - \delta)
\]
The effect of the low-criticality relative deadline
A task set $\tau$ is schedulable if both $A$ and $B$ hold:

- **A**: $\forall \ell \geq 0 : \sum_{\tau_i \in \tau} dbf_{LO}(\tau_i, \ell) \leq sbf_{LO}(\ell)$
- **B**: $\forall \ell \geq 0 : \sum_{\tau_i \in HI(\tau)} dbf_{HI}(\tau_i, \ell) \leq sbf_{HI}(\ell)$

Is there a valid assignment of $D_i(LO)$s to each high-criticality task $\tau_i$ such that both $A$ and $B$ hold?
SHAPING THE DEMAND OF THE TASK SET

![Graph showing the demand of the task set over time interval length (\(\ell\)). The graph plots two sums: \(\sum dbf_{HI}\) and \(\sum dbf_{LO}\). The \(\sum dbf_{HI}\) is represented by a red line, and the \(\sum dbf_{LO}\) by a blue line. The demand increases as the time interval length increases.]
SHAPING THE DEMAND OF THE TASK SET

![Graph showing demand shaping for high and low criticality tasks over time intervals.](image)
SHAPING THE DEMAND OF THE TASK SET

\[ \sum \text{dbf}_{\text{HI}} \]

\[ \sum \text{dbf}_{\text{LO}} \]
Shaping the demand of the task set

\[ \sum \text{dbf}_{\text{HI}} \]
\[ \sum \text{dbf}_{\text{LO}} \]

Time interval length ($\ell$)

Demand

0 10 20 30 40 50 60 70 80 90 100

0 10 20 30 40 50 60 70 80 90 100

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Shaping the demand of the task set

\[
\sum dbf_{HI}
\]

\[
\sum dbf_{LO}
\]
Shaping the demand of the task set
SHAPING THE DEMAND OF THE TASK SET

\[ \sum_{dbf_{HI}} \]

\[ \sum_{dbf_{LO}} \]

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SHAPING THE DEMAND OF THE TASK SET

\[ \sum dbf_{HI} \]

\[ \sum dbf_{LO} \]
Evaluation

![Graph showing acceptance ratio (%) vs. average utilization for different algorithms. The graph compares Our, OCBP-prio, AMC-max, Vestal, EDF-VD, OCBP-load, and Naive algorithms. The x-axis represents average utilization ranging from 0.0 to 1.0, and the y-axis represents acceptance ratio (%) ranging from 0 to 100. Different algorithms are differentiated by various markers and colors.]
Evaluation

Probability of high-criticality

Weighted acceptance ratio (%)

Our
OCBP-prio
AMC-max
Vestal
EDF-VD
OCBP-load
Naive

Our
OCBP-prio
AMC-max
Vestal
EDF-VD
OCBP-load
Naive

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Evaluation

Maximum ratio of high- to low-criticality WCET

Weighted acceptance ratio (%)

Our
OCBP-prio
AMC-max
Vestal
EDF-VD
OCBP-load
Naive

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Conclusions

1. Demand-bound functions are useful *also for mixed-criticality systems*.

2. The particulars of mixed-criticality demand-bound functions allow us to easily *shape the demand* to the supply of the platform.

3. Experiments indicate that this approach *performs well*. 
Questions?